Collective Motions of Animals and Robots
May 27-31, 2024 Cargèse France

Poster presentations

Bagal Ojus
Sapienza Università di Roma
Italy

Light Driven BioHybrid Microbots

Biohybrid microbots integrate biological actuators and sensors into synthetic chassis with the aim of providing the building blocks of next-generation micro-robotics. One of the main challenges is the development of self-assembled systems with consistent behavior and such that they can be controlled independently to perform complex tasks. Herein, it is shown that, using light-driven bacteria as propellers, 3D printed microbots can be steered by unbalancing light intensity over different microbot parts. An optimal feedback loop is designed in which a central computer projects onto each microbot a tailor-made light pattern, calculated from its position and orientation. In this way, multiple microbots can be independently guided through a series of spatially distributed checkpoints. By exploiting a natural light-driven proton pump, these bStuttgart
io-hybrid microbots are able to extract mechanical energy from light with such high efficiency that, in principle, hundreds of these systems can be controlled simultaneously with a total optical power of just a few milliwatts.

Bilaï Biloa Kevin
Université Claude Bernard Lyon 1
France

Optimal control of the navigation of brownian particles in disordered environments

At the nanoscale, the navigation of nano-robots [1] and living organisms [2] are hampered both by thermal fluctuations and by the disorder of the environment. To address this challenging task, we investigate the optimal control of brownian particles in the presence of frozen disorder. Our study is based on a lattice model that aims at describing the motion of nanoparticles on periodic crystalline surfaces, and can also be considered as a simple model for Brownian motion in complex nano-scale biological environments. We introduce disorder to account for defects of crystalline surfaces, or for the complexity of a crowded biological environment.

Dynamic Programming is used to obtain optimal navigation policies in uniform and disordered environments. Using a combination of analytical and numerical solutions, we show how the optimal choice of the force is affected by disorder. Future work aims to further explore the efficiency of such policies in different environments and to investigate collective navigation effects.

[1] Novotny, F., et al, Chem, 6, 867 (2020).
[2] G. Li et al PNAS, 105 18355 (2008).

Boccardo Francesco
University of Genoa
Italy

The role of communication in multiagent olfactory search

A vital problem for many living organisms is to find the source of an odor carried by a turbulent flow, e.g., to find food or to escape from a predator. When multiple individuals perform the same olfactory search simultaneously, communication among them can alter the behavior of individuals and potentially increase group performance. We investigate the dynamics of multiagent olfactory search using a simple swarm model inspired by moth behavior, in which each agent has access to two types of information: private information (e.g., smell), which is perceived at a short distance and is not shared with others, and public information (e.g., average swarm direction), which is accessible by other members of the group within an interaction range. We show how carefully tuning the degree of communication among agents can produce a geometric bias in individual trajectories that optimizes the performance of the swarm.

Botta William
New Jersey Institute of Technology
USA

Mass behavior in the zebrafish Danio rerio in light and dark environments

Mass panic, the contagious spreading of a fear response within a group, can lead to disastrous consequences such as stampedes in humans and death spirals in ants. When regulation mechanisms controlling social behavior fail, they can lead to the unchecked spread of adverse behaviors, i.e. the fear response. Mass panic is influenced by various factors including environment and sensory processes. Previous studies have suggested that increasing obstructions and preventing the detection of conspecifics reduces the likelihood of panic spreading. We tested this hypothesis by looking at how the absence of light impacts the spontaneous panic-like behavior that zebrafish (Danio rerio) larvae exhibit when densely packed. Larvae were filmed in circular arenas of various sizes with differing numbers of larvae, keeping group density constant. Arenas were either exposed to constant light or constant darkness. Contrary to predictions, dark conditions were associated with more panic-like events, not less, hinting at a more complex relationship between the visual environment and the modulation of mass panic. Panic-like events also occurred periodically with rest intervals in between, suggesting mass panics can continuously self-propagate after a synchronized rest period. These results suggest that there is more at play than simply detection of conspecifics. Disrupting the resting period and altering other senses in the light and dark could further explain how these factors impact mass panic.

Clark Molly
University of Bristol
UK

Bioinspired lateralisation to improve search in robot swarms

Lateralisation, colloquially referred to as handedness, is common in animals and may improve efficiency in robotics. In groups such as bird flocks, fish schools and robot swarms, diversity in lateralisation may be particularly beneficial: having individuals that are more sensitive to stimuli on their left and others that are more sensitive on their right may give the group a greater ability to collectively detect stimuli than groups of non-lateralised individuals. Here we test three-spined sticklebacks (Gasterosteus aculeatus) for visual laterality prior to running group experiments to measure search and detection in fish shoals (using a previously established method from MacGregor et al 2020 Nat Comms). From this, we compare the efficiency of the shoal at detecting a food stimulus to their composition of absolute and relative laterality. We can also gain information about how these groups organise themselves when individuals differ in relative laterality, and how efficiency at the task compares to/impacts group cohesion. Findings from these experiments will then be applied to test how lateralisation in swarming robots affects the ability of robot swarms to detect stimuli. Here we will use simulations and a swarm robotics testbed, seeking to improve the capability of robot warms which have a range of real-world applications.

Córdoba Alfons
LPTM CY Cergy Paris Université / CNRS 2
France

Emergence of learning and flocking through reinforcement

In this project we study what collective and global patterns emerge when cohesion is used as the low level principle or drive of agents that interact locally in real space and in the behavioural space. We define cohesion defined as the avoidance of losing neighbours. Unlike previous works, we introduce a cone of vision that breaks the symmetry of interactions. Rather than restricting their behaviour by introducing forces or potentials we let them choose what direction to choose. Their behaviour evolves in time according to their

unique experiences and ability to keep cohesion. We study sytems with perception based on the velocity of the neighbours on the one hand and their positions, on the other. When noise is applies is starts to disturb the order and the collective learning but not necessarily equally. Lastly, noise leads to behaviours different to the expected ones.

Dagher Maya
Max Planck Institute of Animal Behavior
Germany

Evolution of cooperative swimming in robotic fish

The synchrony of animals moving in viscous fluids can significantly impact their power efficiency. In the case of fish schools, individuals can adjust the relative phase difference between their tailbeats and those of their neighbours to leverage hydrodynamic effects. However, an unresolved question is whether fish optimize motion synchronicity for individual or collective benefit.

To address this gap, we developed a game theory model of cooperative swimming, focusing on pairs of side-by-side, coplanar fish. Utilizing power data from biomimetic fish, we constructed a payoff matrix to explore different tailbeat-phase update strategies. We identified a subset of simple strategies that consistently lead to fish converging to synchronizations optimizing group power efficiency, rather than individual performance. This suggests that cooperative swimming may arise from self-interested decision-making using relatively low-level percepts.

To validate these findings, we implemented these strategies in robotic fish swimming in a laminar flow tank. The robotic fish adjusted their tailbeat phase in real-time based on power cost readings, allowing us to assess the reproducibility of cooperative swimming under real hydrodynamic noise conditions.

Our results shed light on possible underlying mechanisms driving cooperative movement in low Reynolds number environments and underscore the importance of noise structure on phenomena emerging from animal collectives.

Donini Giacomo
La Sapienza Univ. Roma
Italy

Torque response in the flagellar motor of light-powered E. coli

The bacterial flagellar motor (BFM) is a rotating nano-motor embedded in the cell membrane that rotates the flagellum, generating self-propulsion. Capable of rotating at up to hundreds of Hertz, the bacterial flagellar motor is one of the most powerful and efficient molecular motors in nature, but it still lacks a satisfactory model to explain its molecular functioning. The relevant quantity that characterises the motor is the torque delivered at different frequencies. Using rotating optical tweezers, we impose the frequency of the motor and simultaneously measure the torque. We find new experimental evidence for a discontinuity of torque across the zero-frequency stall point, reopening a debate that was thought to be closed.

Fausti Giordano
La Sapienza Univ. Roma
Italy

Phase Separation in Active Matter Systems: Non-Equilibrium Fingerprints

In this talk, I will present a minimal field theoretical model (AMB+) that is used to describe the phase separation of a diffusive, scalar field in active systems. The model is a generalization of equilibrium model B, describing the vapor-liquid phase separation in passive systems. We will see how, by adding activity to Model B, the nature of the liquid-vapor bulk phase separation changes. After reviewing all the various kinds of phase separation predicted by AMB+, I will present a minimal effective model of diffusing vapor bubbles that mimics the behavior of AMB+, encapsulating its essential features.

Fiorese Andrea
University of Trento
Italy

How swarms of different sizes respond to noise: diffusive behaviour and statistical analysis of the collective dynamics.

We propose a new microscopic model based on a system of interacting stochastic differential equations of Langevin-type for describing the collective dynamics of a self-propelled particle swarm. In many of the available models the swarm dynamics is settled in the overdamped regime. Here we formulate a stochastic dynamical process by adopting an underdamped approach. In our model we combined three well known forces: first a Morse-type potential, that accounts for social interactions within the swarm, a friction force that has the role of a restoration term for the microscopic dynamics, and finally, an alignment term that stimulates particles to assume the velocity of their neighbours via a weighted average procedure. This alignment term has been proven to have a central role in leading the swarm dynamics. We first derive the equation of motion for the swarm center of mass, which clearly shows how the number of particles rescales the noise affecting the collective dynamics. We found that the finiteness of the swarm is responsible for the emerging of random fluctuations in the motion of the center of mass, which is ruled by a stochastic motion as well. Afterwards, we identify three different dynamical regimes for the swarm dynamics that correspond to the balancing between the alignment and friction effects. We derived the equations for the mean squared displacement of the center of mass in order to analyze the diffusive behaviour of the swarm. Finally, we report output of numerical simulations we have performed to support the theoretical results.

Font Massot Narcís
University of Konstanz
Germany

The effect of complex social environment on the collective behavior of nematodes

Collective behavior is observed across a wide range of biological systems. The individuals' interactions with their social environment and the ability to recognize and distinguish between individuals play a crucial role in shaping the collective state of the system. However, little is known about the mechanisms and dynamics of these processes and how they influence the collective outcome.
We use C. elegans and other nematode species as a model system to comprehend how social interactions and self-recognition affect the collective behavior of heterogeneous groups. This experimental system offers the opportunity to control and measure the genetic and behavior characteristics of individuals within a group to study the collective behavior of different group compositions. We conduct three sets of mixed populations experiments: First, we investigate solitary and aggregating C. elegans strains to assess the social context-dependent collective dynamics. Second, we investigate two aggregating C. elegans strains to determine how genetic differences affect aggregation. Finally, we ask these two sets of questions in a different nematode species, P. pacificus, which exhibits complex social behaviors such as self-recognition to avoid cannibalism behavior towards kin and a unique aggregation process that has evolved independently from those of C. elegans. Through our work, we seek to answer how individual identities and interactions shape the group-level behavior of heterogeneous groups.

Gagliardi Luca
University of Genova
Italy

Learning how to crawl

We present and discuss a simple model of a 1D crawler which, for a given internal compression/elongation wave, can only control its suckers. The suckers can anchor to a flat substrate or remain idle.
Using tabular Q-learning, we test how different control designs can learn to achieve efficient (i.e. fast) crawling. We show that:
1. Crawling can be learned in a pure multi-agent setting where each sucker is considered an independent agent with no long range representation of the system, and with or without constraining each sucker to adopt the same strategy (hive update).

2. Moving to a more complex control, where a control center (ganglion) controls an assembly of suckers, better coordination can be achieved (faster crawling).
3. The complexity of this second setting increase exponentially with the number of suckers, and learning becomes prohibitive for large ganglia. We show that several smaller ganglia can be used to successfully control dense tentacles without exponentially exploding the computational complexity.
Our results show that agents physically connected to one another can learn a collective action, even if they do not communicate. However, a higher organization may emerge due to tradeoffs between computational requirements and action coordination. The model could help understanding the transition from loose nervous systems into structured networks, under the pressure of achieving coordinated actions.

Gardi gaurav
Max Planck Institute for Intelligent Systems
Stuttgart Germany

Microrobot collectives with reconfigurable behaviours and functions

Ranging from bird flocks to bacteria collectives, self-organising systems are ubiquitous in nature. These systems exhibit fascinating patterns that extend both in space and time. Inspired by the natural systems, various robotic swarms have been developed. At macroscopic scales, artificial systems primarily utilise computational capabilities to form swarms. However, at the micro-scale, the artificial systems are limited in their abilities due to their minimal computational capabilities. In this talk, I will present an experimental system of magnetic micro-disks in which programmable physical interactions and an external driving jointly generate diverse self-organised behaviours. The mutual interactions among the micro-disks can be tuned to form diverse collective behaviours, ranging from isotropic (rotating and static collectives) and anisotropic (chains) behaviours, to a gas-like behaviour consisting of self-propelling pairs. A uniform magnetic field is used to generate transitions among various behaviours and enable various robotic functions. The micro-disks can transition on demand from a reciprocal regime where disks exert equal and opposite interactions, to a non-reciprocal regime that is typical of biological systems. Overall, this talk highlights our system's capability to act as an adaptable and versatile model system for dynamic self-organisation and for development of versatile microrobot collectives.

Giorgetti Carlo
Univ. Roma,
Italy

The motility of bacteria E.coli
The motility of bacteria E. coli represents one of the most studied examples yet to be investigated. When the density of these bacteria reaches a critical value, a collective dynamic occurs that is known as active turbulence [1,2]. In this state, the bacteria's motion appears chaotic, similar to that of a fluid in classical turbulence, with the presence of vortices of finite dimensions. It has been shown experimentally that this motion can be rectified through geometric confinements [3]. In this poster, I show how to control such dynamics through light. With photokinetic bacteria and a suitable experimental setup, it is possible to modulate activity with great spatio-temporal control. By activating a circular region, a coherent collective dynamic of limited duration is created, with a single vortex within it. I study the characteristics of this phenomenon as a function of the size of the light confinement and certain properties such as its mean lifetime and propose possible explanations.
References:
[1] Sokolov et al. Phys. Rev. Lett. 98, 158102 (2007).
[2] Dunkel, J. et al., Phys. Rev. Lett. 110, 228102 (2013).
[3] Wioland, H. et al.,Phys. Rev. Lett.110, 268102 (2013).

Iyer Priyanka
Forschungszentrum Jülich
Germany

Emergent collective motion of active agents at a three-way crossing

In pedestrian navigation and crowd control, scenarios like the Shibuya Crossing in Tokyo or mall intersections pose important questions regarding self-organization of semi-dense pedestrian crowds and the design optimization of facilities. In this work, the emergent collective motion of active agents at a three-way

pedestrian crossing is studied by Langevin simulations of cognitive active Brownian particles (ABPs) with directed visual perception, goal following, and self-steering avoidance. Depending on the strength of the maneuverability
(the maximum allowed torque to change the direction of motion) and the vision angle, different types of pedestrian motion emerge, such as local wiggling-through behavior, pedestrian clustering, and localized flocking. The mean squared displacement and velocity auto-correlation are studied to characterize the motion of the pedestrians by introducing an effective noise model. Variation of the crowd density of pedestrian traffic leads to rich differences in the collective behavior, such as the development of rotating flows at the intersection. Our research provides valuable insights into the importance of vision angle and self-steering avoidance on pedestrian dynamics in semi-dense crowds (where volume-exclusion interactions are not relevant).

[1] Negi, Rajendra Singh, Priyanka Iyer, and Gerhard Gompper. "Controlling Inter-Particle Distances in Crowds of Motile, Cognitive, Active Particles." arXiv preprint arXiv:2402.03851 (2024).

James Martin
University of Genoa, Italy

Turbulence and Pattern Formation in a Minimal Model for Active Fluids

Living and nonliving active matter, ranging from flocks of birds to active colloids, exhibits a fascinating range of physical phenomena such as order-disorder transitions, chaotic states and pattern formation. This poster presents our theoretical and numerical analysis of turbulence and pattern formation in active fluids. We demonstrate that a minimal phenomenological model for active fluids not only captures an active turbulent phase but also results in an active vortex crystal (AVC) phase that emerges after an extended turbulent transient. We systematically characterize the phase diagram of this active fluids model and explore how the AVC, which has been recently confirmed through experiments in bacterial systems, transitions into the turbulent active fluid. Inspired by hydrodynamic turbulence theory, we develop a statistical closure theory for velocity correlations in active turbulence which is validated by simulation results. Additionally, our recent collaborations reveal that active turbulence fundamentally differs from hydrodynamic turbulence due to the presence of superdiffusion caused by Lévy walks. However, at asymptotic levels of activity, a regime of universal scaling emerges in active turbulence, similar to hydrodynamic turbulence."

Kang Youn Jae
Max Planck Institute of Animal Behavior
Germany

Quantification of baseline C. elegans aggregation on food and the kinetics affecting the underlying probabilities

C. elegans exhibits various forms of collective behaviour such as aggregation, pattern formation, and towering. Of these, aggregation of worms feeding on a bacteria food patch is the most well-studied. Despite detailed elucidation of the molecular and the neuronal mechanisms of aggregation, existing literature adopts only a simple binary classification of the aggregation phenotype: aggregating vs. non-aggregating. This fails to provide an objective reference that forms the basis for further comparison and probabilistic description of the behaviour.

Here, we present the baseline measurement of aggregation under various worm densities using the canonical “non-aggregating” lab strain N2 as a reference. We found that N2 worms do form aggregates above a certain density, and that this baseline aggregation increases with higher density. The same trend was observed in the canonical “aggregating” strain npr-1, which suggests strain-independent density effect on aggregation. The measured baseline formed a quantitative framework for the following analyses.

We then compared the movement of npr-1 against N2, to identify kinetic features that increase aggregation probability in npr-1. We found that enhanced deceleration in npr-1 following a pairwise encounter event increases aggregation probability. Agent-based simulations confirm that tuning density and deceleration reproduces the observed trends in C. elegans aggregation. Together, these findings show that C. elegans aggregation can be modelled as a multivariable function of particle density and deceleration. Development of this linear model is currently in progress to provide a quantitative description of the association.

Kahn Muhammad Turab Ali
Max Planck Institute for Intelligent Systems
Stuttgart

Perturbing Collectives of Active Droplets

Active droplets are minimalistic model representations of single-celled microorganisms, exhibiting similar behaviors like locomotion, sensing, and chemotaxis. At higher number densities, these droplets self-organize into pairs, chains, and clusters (rotating or static) alike various single-celled microorganisms. As these behaviors are autonomous, there is limited room for external perturbation and control. Here, we propose a strategy to perturb the self-assembled droplets, to study the stability of the trapped states and finally, the dynamic restoration to the original self-assembled state. These findings provide insights into the underlying microscopic mechanisms for such droplet assemblies and further the utilization of active droplets as a model system for single-celled microorganisms.

Kirchmair Bernhard
Ludwig-Maximilians-Universität München,
Germany

Quantification of RNA content in Lipid Nanoparticles using Fluorescence Correlation Spectroscopy

Lipid nanoparticles (LNPs) emerged towards the most promising vectors to deliver messenger RNA (mRNA) to mammalian cells. Advanced strategies using multi-component nucleic acid species require a reliable quantification of the stoichiometric ratios. Quantitative knowledge about content and ratios will allow the delivery of genetic programs for regulated gene expression. Therefore, this project seeks to quantify the mRNA-content when varying the LNP size and surface composition. Employing Fluorescence Correlation Spectroscopy (FCS) measurements, assisted by Dynamic Light Scattering (DLS), both size and concentration of LNPs in solution can be estimated, allowing to obtain the average number of RNA molecules per particle. In this work, also mRNA loading dependent on LNP size was determined. Based on this, using Fluorescence Cross Correlation Spectroscopy, the stoichiometric ratio of short interfering RNA (siRNA) and mRNA, both fluorescently labeled, was determined.

Laciel Alonso
University of Navarra.
Spain

Robotic Traffic Dynamics

We present experimental findings concerning the collective motion of a group of robots interacting through position sensors. Our study successfully replicates stop-and-go waves reminiscent of traffic jams, along with the fundamental diagram or speed-density relation commonly observed in such systems. The innovative design of our system contributes to enhanced experimental stability and repeatability, facilitating extended experimental durations and enabling a comprehensive statistical analysis of global dynamics. Notably, beyond a critical density, we observe significant divergences in both average jam duration and the average number of participating robots. Leveraging this observation, we accurately delineate the transition between three distinct scenarios: a free flow under dilute conditions, an intermittent flow at intermediate densities, and a fully congested system at high densities. This discovery not only provides valuable insights but also underscores the versatility of our robotic system in modeling more complex scenarios.

Ma Qimin
Sorbonne University
France

Fish swimming, collective dynamics, altered flows

We study a group of tetra fish (Hemigrammus rhodostomus) in a swimming channel in the wake of a cylinder-shaped obstacle. The swimming test section is 25cm long, 10cm wide, and has a 5cm depth. The fish body length is around 4cm. The cylinder diameter is 14mm and the flow speed ranges between 2 and 18

cm/s, which gives Reynolds numbers for the wake flow between 280 and 2500. A strong vortex wake is therefore present with which the fish interact. We will present results on swimming tests with groups of 2, 3, 4, 5, and 6 fish where video recordings from top and side views are used to examine the group spatial organization in the swimming area. Quantitative information on the group cohesion and its dependence on the incoming flow velocity is obtained by tracking the positions of the fish during each swimming test.

Marcolli Francesco
Università degli Studi di Genova
Italy

Multi-sensor odor predictions with imperfect proprioception

In this poster, I will address the question of how a multitude of chemical sensors can collectively infer the location of a chemical source. In our setting, odor develops into a convoluted and sparse cloud, due to turbulent transport, and each sensor measures odor concentration at its location. I will first discuss the ideal case where sensors have perfect knowledge of their relative position and combine their measures using Bayesian inference. I will then show that, in general, errors in the relative position of the chemoreceptors affect prediction accuracy. However, accuracy can be restored or even improved under specific circumstances, if these errors are accurately accounted for. Our results set the basis for understanding whether and how imperfect proprioception may affect the olfactory behavior of octopuses and other animals with distributed nervous systems.

Paramanick Somnath
IIT Bombay
India

Emergence of run-and-tumble like dynamics in coupled active Brownian robots.

Motility is one of the most remarkable features of living organisms and active particles. Often its emergence is a complex interplay of various components that are also active. Even though there are numerous examples of living and artificial active particles, there is a lack of detailed understanding of how individual active components, in conjunction, give rise to such complex motility characteristics. Here, we perform experiments on a "compound robot" composed of two motile robots connected with a rigid rod. The robots are centimeters-long disk-shaped programmable active particles with off-centered pivot points around which the rod can freely rotate. A pivot located at the left/right side of the robot's orientation introduces right/left-handed chirality in the robot dynamics.
We show that when individual robots are programmed to follow active Brownian motion, the left- right chiral compound robot can display run-and-tumble-like dynamics. We find that the
spontaneously evolving run and tumble events correspond to the states where the velocities of the two robots are aligned and misaligned, respectively. We find non-trivial run-time and tumble angle
distribution in the dynamics. We also discover a systematic dependence of run-time statistics on the rotational noise of the individual robots. Overall, we demonstrate how complex motility behaviour arises in an active particle composed of multiple active components and possible strategies to tune such a motion.

Ramaswamy Sree Subha
Tata Institute of Fundamental Research, Bangalore
India

How do blind termites blind skyscrapers?

Mound-building termites are renowned architects of the insect world, constructing vast and complex structures despite lacking image-forming eyes. Their ability to efficiently repair damages to their mounds has long intrigued scientists, raising questions about the underlying coordination mechanisms. Our study delves into the cues that guide termites to specific construction or repair sites. Through a series of meticulously designed experiments, we observed a distinct preference of termites for soil that has been recently manipulated during mound repair, over unaltered soil. Intriguingly, when chemical extracts from this freshly worked soil were introduced into naive soil, the termites exhibited a similar preference, indicating a chemical basis for their choice. Our findings illuminate how termites employ a sophisticated strategy to chemically encode spatial and temporal information within their environment. They adeptly utilize both volatile and non-volatile compounds to embed critical environmental contexts, such as repair sites or distinguishing between self and foreign mounds. This study also uncovers a caste-based specialization in chemical cue perception among major and minor worker termites, highlighting an intricate division of labor and sensory specialization. The results of our research shed light on the nuanced and multifaceted ways termites communicate and coordinate their building activities. It reveals a novel paradigm of chemical communication, demonstrating how termites use a limited set of chemicals in versatile ways to encode complex functional contexts, enabling them to construct and maintain their impressive structures over time. This research not only advances our understanding of termite social behavior and communication but also offers potential insights for the development of bio-inspired systems in robotics and artificial intelligence.

Serna Horacio
Universidad Complutense de Madrid
Spain

Collective behavior of squirmer-like microalgae under the effect of a gravitational field

Microalgae have evolved mechanisms to self-propel. The interactions between different types of Biological Microswimmers (BM) are relevant in natural processes such as the regulation of carbon and oxygen biogeochemical cycles and the toxin released by phytoplankton blooms under certain environmental conditions. In Nature, BMs swim through complex porous media where they interact with passive and active agents, and are subjected to external fields, such as gravity. To tackle the existing lack of a full understanding and control of the collective motion of a suspension of BM, we have studied structural and dynamical features of a suspension of squimer-like microalgae under confinement, explicitly taking into account both hydrodynamics and gravity.

Ventrella Francesco Michele
University of Turin
Italy

Numerical simulations of model swimmer

This paper focuses on the Immersed Boundary (IB) method for simulating swimmer motility. The IB method has found applications in various biological fluid dynamics problems and was initially developed to simulate blood flows in the heart. It has been applied to scenarios such as platelet aggregation during blood clotting and animal locomotion. In essence, the method is suitable for modeling any elastic body in a flow. It treats the elastic material as part of the fluid, applying additional forces due to stress on the body's surface. The IB method allows the straightforward application of Navier-Stokes solvers to complex flow geometries without the constraint of a boundary-conforming grid. The method developed by Peskin proves invaluable for simulating the motion of flexible bodies in a fluid and their interactions. The fluid dynamics are described by Eulerian variables on a fixed numerical grid in the fluid domain, while the motion of swimmers is described using Lagrangian variables on a freely moving mesh composed of representative material points. The presence of the body is represented by a punctual forcing that is spread to the nearest Eulerian nodes, updating the fluid velocity equation as external forcing. The model has been compared to Jeffery's particle and applied to the study of motility of a great number of swimmers.

Wittmann Martin
TU Dresden
Germany

Motion of active micro rods: from individual rods to interactions

In this work the behaviour of catalytically active micro rods is analysed. When immersed in a hydrogen peroxide solution, the rods show motion perpendicular to their long axis. First, the behaviour of individual rods is observed. Here, the motion can be strongly influenced by the concentration of hydrogen peroxide but also by the substrate. After that, also interactions between individual rods are analysed. These interactions can take place over relatively large distances and are mostly of repulsive nature. In future, the behaviour of larger groups of rods will be analysed, which could lead to interesting collective effects. First experiments showed an alignment of multiple rods moving in the same direction.

Wu Wenhan
Humboldt Universität zu Berlin, germany
Tsinghua University, Beijing, China

How movement dynamics affect cascading behavioral contagion in animal groups

Complex behavioral contagion in collective evasion of mobile animal groups can be predicted by reconstructing quantitative interaction networks. Because of the fast speed of the sudden acceleration maneuvers and the resulting time-scale separation, the underlying interaction networks has been previously assumed to be static, determined by the spatial structure at the onset of the collective escape response. Although this allows reasonable prediction of individual escape events, this idealization does not account for the dynamic changes of the spatial network structure. Here, we propose a spatially-explicit, agent-based model for the coupling between behavioral contagion and the network dynamics originating from the spreading movement response. We explore the impact of movement parameters (speed, initial directionality, and directional noise) on average cascade size. By conducting numerical simulations for different density levels, we show that increasing escape speed suppresses the cascade size in most cases, that the cascade size depends strongly on the movement direction of the initially startled individual, and that variability in the direction of individual escape movements (rotational noise) can promote the spread of behavioral contagion through spatial groups. Our work highlights the important role of movement dynamics in cascading behavioral contagion, and facilities our understanding of rapid coordinated response and collective information processing in animal groups.

Yan Mingqi
Ludwig-Maximilians-Universität München
Germany

A Stochastic Bubble Model in MIPS Active systems

Motility-Induced Phase Separation (MIPS) is a notable phenomenon in which self-propelled particles undergo phase separation solely due to their intrinsic motility. This behavior starkly contrasts with passive systems, where active systems constantly form bubbles in liquids. Here, we introduce a stochastic bubble model to elucidate the changes in bubble area within Active Brownian Particle systems. We demonstrate that the bubble-area evolution can be described by a Langevin equation. Notably, this equation characterizes a unique category of stochastic systems: while it possesses an absorbing state, it concurrently maintains a stable nonequilibrium steady state distribution of areas.

Nicolazo-Crach Victoria
Université Paris Saclay, France

Controlled collective motion of algae for targeted cargo delivery

Active particles are inherently out-of-equilibrium systems, able to uptake energy from their environment and convert it to motion. Potential applications of active particles such as micro-swimmers and micro-robots in bio-medicine are developing rapidly [1]. For example, Chlamydomonas Reinhardtii (CR) is a micro-swimmer whose orientation can be dictated by a light gradient in its environment (phototaxis). It is known that a collective motion, triggered due to the phototaxis of a population of CR, generates bioconvective structures that affect the fluid medium [2]. The purpose of this study is to control the motion of algae swarms and resulted bioconvection in order to achieve a guided transportation of microscopic objects submerged in the algal suspension. High concentrations of algae and microparticles were confined in a small square Hele-Shaw cell surrounded by a series of LED allowing us to apply different well-controlled gradients of light in a quasi-2D horizontal domain. It was shown that the microparticles can be transported to a target zone by controlling the displacement of algal bioconvective structures.

[1] A. I. Bunea, D. Martella, S. Nocentini, C. Parmeggiani, R. Taboryski, and D. S. Wiersma, Adv. Intell. Syst. 3,
2000256 (2021).

[2] J. Dervaux, M. Capellazzi Resta, and P. Brunet, Nature Phys 13, 306–312 (2017).

Yi Wenfeng
University of Bristol, UK
Tsinghua University, beijing, China

Human morality difference when programming and actually operating swarm robots

Autonomous machines (AMs) are poised to possess human-like moral cognition, yet their morality is often pre-programmed for safety. This raises the question of whether the morality intended by programmers aligns with their actions during actual operation, a crucial consideration for a future society with both humans and AMs. Investigating this, we used a micro-robot swarm in a simulated fire scenario, with 180 participants, including 102 robot programmers, completing moral questionnaires and participating in virtual escape trials. These exercises mirrored common societal moral dilemmas. Our comparative analysis reveals a "morality gap" between programming presets and real-time operation, primarily influenced by uncertainty about the future and heightened by external pressures, especially social punishment. This discrepancy suggests that operational morality can diverge from programmed intentions, underlining the need for careful AM design to foster a collaborative and efficient society.

Ziepke Alexander
Ludwig-Maximilians University Munich
Germany

Communication in active matter: From chemically interacting cells to acoustic microrobots

In active matter systems, communication between the constituting agents plays a crucial role in the self-organization of collective behavior. Different organisms have developed various communication strategies to control their cooperative responses. For instance, social amoeba use chemical signaling to form localized aggregates in response to starvation, insects such as ants secrete pheromones for navigation, and bats and birds employ acoustic signals to form cohesive swarms. Our research focuses on how chemical and acoustic communication enables the formation of collective states with cooperative functionality, a targeted specification of the units, and the control of a coordinated response. We show that the collective states use mutual information processing to control their responses to environmental cues [1]. In particular, acoustic signaling of oscillatory agents leads to the formation of synchronized localized clusters and collectively propagating snake- and larva-like structures with distinct acoustic signatures. By emitting acoustic waves, these emergent structures can sense environmental changes, such as approaching reflective objects, and respond with a coordinated change in phenotype.
This study provides insights into design principles for unsupervised communicating microrobots that form adaptive, multi-functional collective structures with population-level cognitive capabilities.

[1] A. Ziepke, I. Maryshev, I.S. Aranson, and E. Frey. Multi-scale organization in communicating active matter. Nat Commun 13, 6727 (2022).
